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At-Sea Measurements of Diver Target Strengths at 100 kHz: Measurement Technique and First Results

By R.D. Hollett, R.T. Kessel and M. Pinto

1 INTRODUCTION

During a recent at-sea trial of a diver detection system, the opportunity was taken of developing a technique for *in-situ* measurement of diver target strengths. The technique was based on making the diver perform circular manoeuvres in front of the sonar to present all aspect angles to the sonar. The diver was made to perform the circular manoeuvres by means of tethers attached to the diver, from a seabed anchor and a surface float, ensuring constant radius and depth about a fixed point. Otherwise, the diver was uninhibited in limb movement, attitude, exhalation rate.

The experimental set-up employed, the procedure employed, how the set-up complied with the far-field requisite and how the multipath effects were eliminated are discussed in Sect. 2. A transformation of coordinates (by change of origin), the inverse transformation and how the transformation was employed in aspect angle estimation are discussed in Sect. 3. An application to the case of a diver with air tanks, exhaling clouds of bubbles into the water column, and how a target tracker was developed to locate the diver are discussed in Sect. 4. The first results are presented in Sect. 5.

2 EXPERIMENTAL SET-UP, PROCEDURE, VALIDITY

The experimental set-up was centred around 'Cerberus', a 100 kHz diver-detection system manufactured by Qinetiq, U.K.. The system was made up of an Offshore Unit (OSU), and a Shore-Side operator interface (SSU). The Offshore Unit was made up of transmit/receive (TX/RX) rings, 0.5 m in diameter (approximately), mounted above the wet-end electronics, giving full 360-degree coverage. The transmit ring was made up of 12 sectors, each sector giving 30-degree coverage, independently switchable. The receive ring was made up of 256 equispaced staves (each stave made up of 2 elements, the lower element double the height of the upper), giving horizontal beamwidths of typically ±1.8 deg and vertical beamwidths of typically ±9 deg (lower and upper elements combined).

The Offshore Unit was mounted on a 3-m high tower (raising the transmit/receive rings to a height of 4 m), deployed in some 10 m of water and cabled to the Shore-Side Unit in a container lab. nearby (Fig. 1).

The sonar was made to transmit CW pulses at 100 kHz, with 1-ms duration and at a ping-repetition rate of 1 Hz. An anchor was dropped some 20 m in front of the sonar, the diver tethered to the anchor and to a surface float. The tethers were arranged to make the diver proceed around the anchor at a fixed distance of some 5 m and at mid-

water depth (5 m), remaining within the vertical transmit/receive mainlobes throughout the manoeuvre.

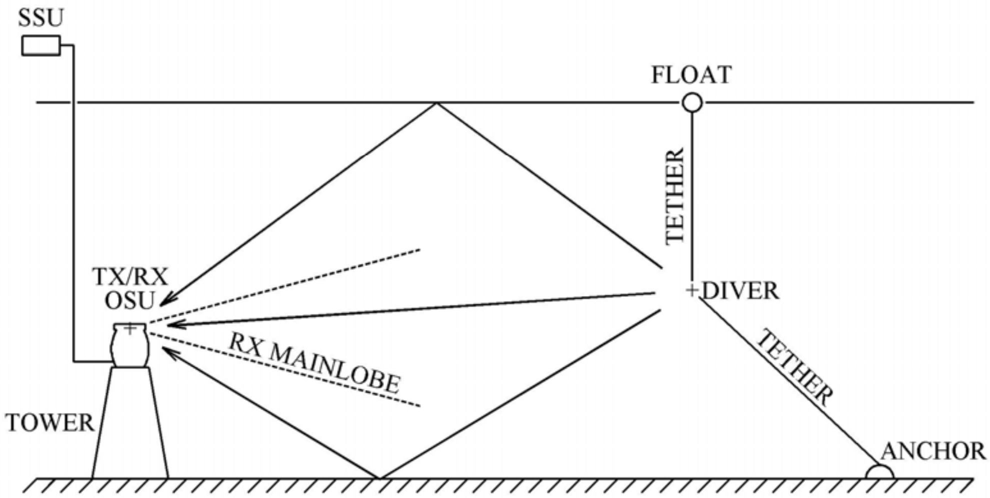


Fig. 1. Experimental set-up centred around ‘Cerberus’, a 100 kHz diver-detection system.

The validity of the arrangement was based on being in the far fields of the transmit/receive rings and in the far field of the scattering from the diver. The field of the transmit ring was made up of the fields of the sectors, each sector sufficiently limited in size as to guarantee a far field at ranges of a few meters. The field of the receive ring was made by beamforming with a subset of (typically 64) staves (oriented according to beam direction), sufficiently limited in size as to guarantee a far field at ranges beyond 10 m. The scattering from the diver was judged to be in the far field on the basis of domination of the scattering by returns from parts of the diver’s torso and breathing apparatus, of limited size.

The elimination of the multipath effects was guaranteed by the limits on the diver’s range, i.e., 20±5 m (multipath returns at high angles), and the receive vertical directivity (multipath returns in the sidelobes).

3 TRANSFORMATION OF COORDINATES

A transformation of coordinates was employed to estimate the aspect angle of the diver with respect to the sonar. In addition, the transformation was found to be important in the development of a target tracker for the application to a diver with air tanks (Sect. 4).

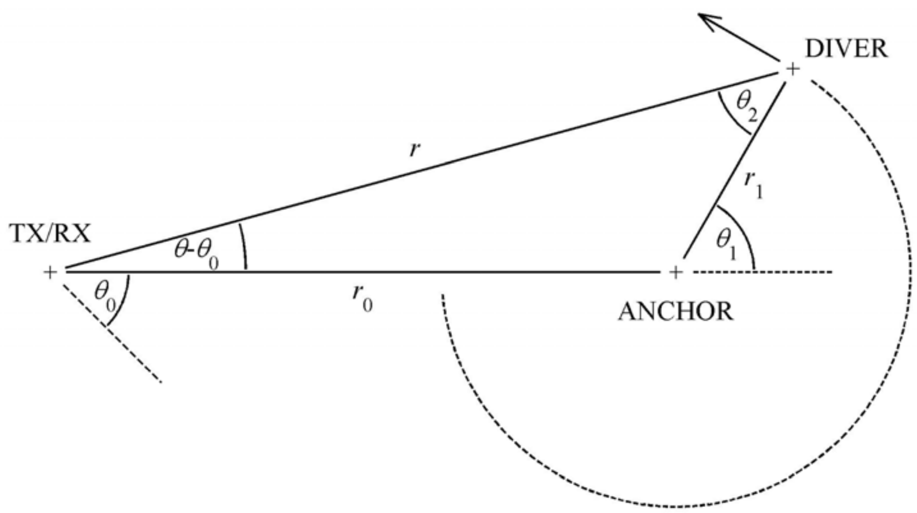


Fig. 2. Nomenclature used for the transformation of coordinates.

In essence, the transformation was used to effect a change of origin from the centre of the transmit/receive rings to the centre of the diver's circular manoeuvre

$$r_1 = \left(r_0^2 + r^2 - 2r_0 r\cos(\theta-\theta_0)\right)^{1/2}, \qquad (1)$$
$$\theta_1 = \tan^{-1}\left(\frac{r\sin(\theta-\theta_0)}{-r_0 + r\cos(\theta-\theta_0)}\right),$$

i.e., (r_1, θ_1), the diver's position with respect to the anchor, expressed in terms of (r, θ), the diver's position with respect to the sonar (Fig. 2). In addition, the inverse transformation was found to be important in the definition of a grid for pixel relocation

$$r = \left(r_0^2 + r_1^2 + 2r_0 r_1 \cos\theta_1\right)^{1/2}, \qquad (2)$$
$$\theta = \tan^{-1}\left(\frac{r_1\sin\theta_1}{r_0 + r_1\cos\theta_1}\right) + \theta_0,$$

(Sect. 4). The diver's aspect angle with respect to the sonar was estimated by

$$\theta_2 = \theta_1 - \theta + \theta_0, \qquad (3)$$

and the direction of the diver's motion estimated by subtracting or adding 90 deg, according as a clockwise or anti-clockwise procession around the anchor.

4 APPLICATION TO A DIVER WITH AIR TANKS

The feasibility of the application was based on locating the diver in the sonar's beams. The location of the diver by visual inspection of successive pings, unaided by a tracker, was found to be unreliable. Instead, a tracker was developed to display the diver's position.

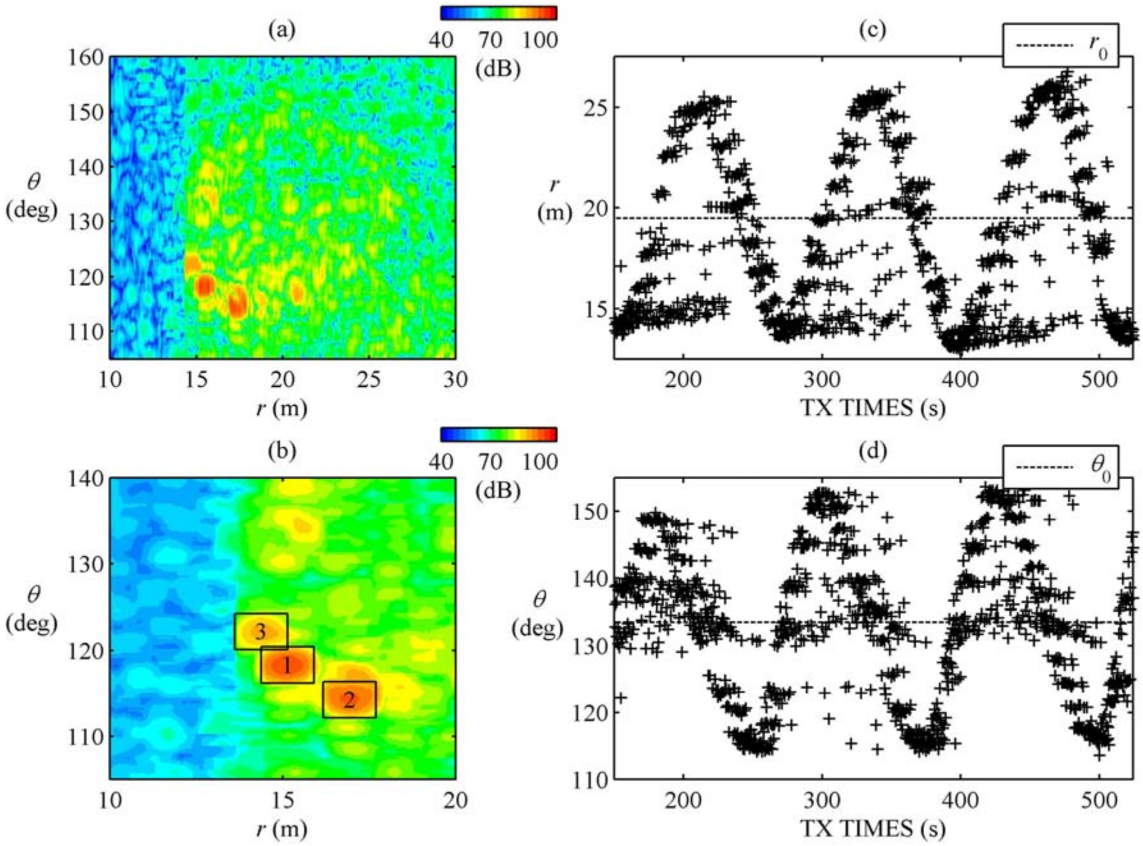


Fig. 3. Estimates of echo levels and locations.

The sonar's beams were formed in a sector fanned out over the diver's track (Fig. 3a). The sector was oversampled in azimuthal angle, i.e., the beams were formed at azimuthal intervals of a fraction of the beamwidth (intervals of 0.175 deg), to enhance the accuracy of bearing estimates. The beams were subjected to a moving-averager filter in time (Fig. 3b). The filter in the averager was set to correspond in length to the pulse duration (1 ms). The peaks in the averager's output were used as estimates of echo levels and locations. The estimates of echo locations were clustered in correspondence with the diver's exhalations, for the most part (Figures 3c and d).

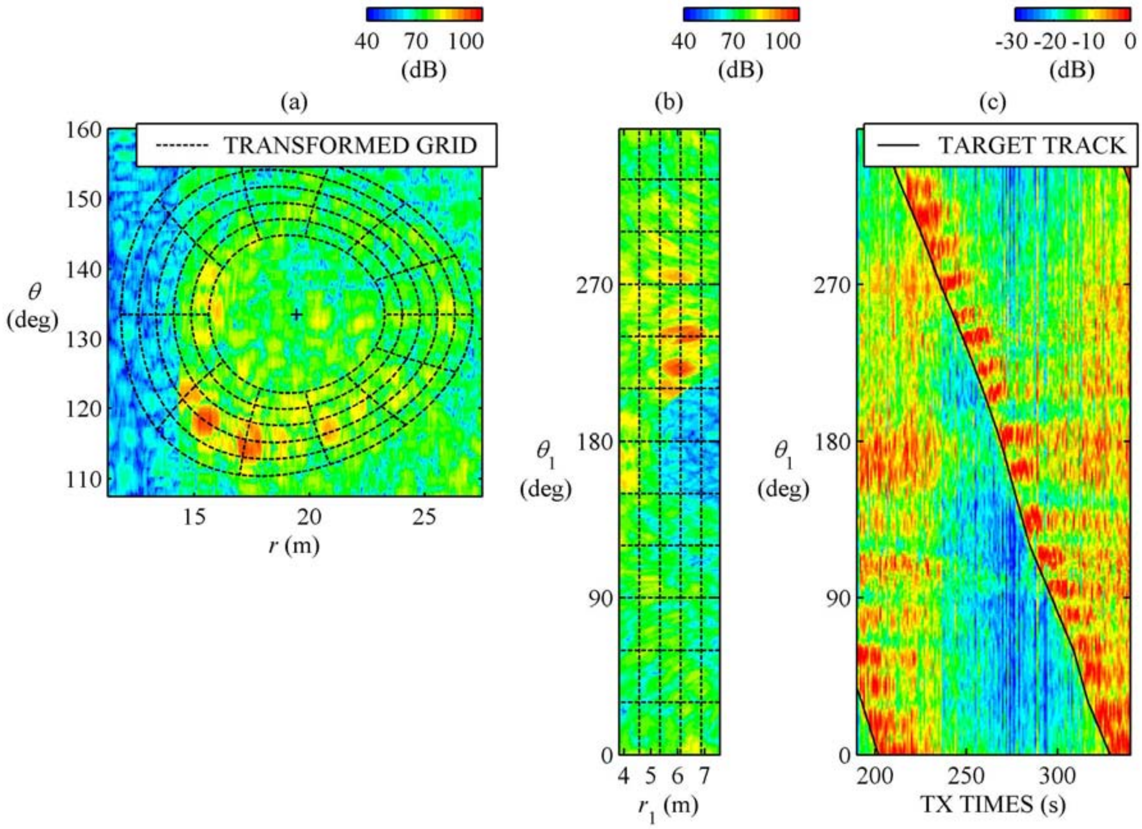
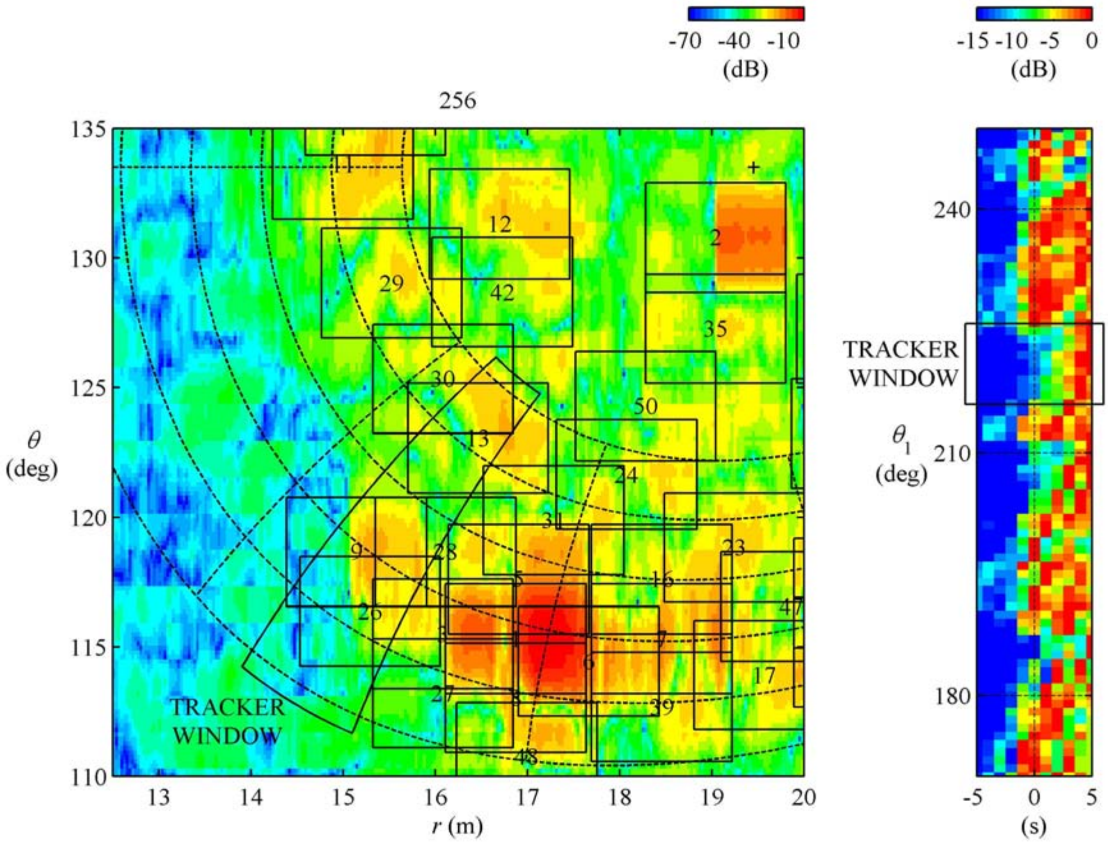


Fig. 4. The development of the tracker.

The correspondence of the exhalations with the diver's position was exploited in the development of the tracker (Fig. 4). The development was based on a change of origin by relocation of pixels from the sonar-centric images to anchor-centric images (Figures 4a and b). The relocation was facilitated by means of a grid in the sonar-centric system. The grid was defined by inverse transformation of a grid in the anchor-centric system (by use of (2)). The pixels in the anchor-centric images were used to make an anchor-centric record of the diver's procession by summing in range and ordering in ping time (Fig. 4c). The record was used to define the diver's track by tracing the onset of the exhalations around the anchor. The track was defined as a series of linear segments located by visual inspection.

The tracker was used to review the sonar-centric images on a ping-by-ping basis (Fig. 5). The diver's position from the tracker was displayed together with the locations of the fifty strongest echoes and a coarse grid (as a visual aid). The diver's position was displayed as a window centred on the position and extended across the track. In addition, the diver's position was displayed together with the anchor-centric record of the diver's procession (Fig. 5, right). The acceptance of an echo as scattered from the diver, not the diver's exhalations, was based on an acceptance criterion: centred in the tracker window, located at the expected distance from the anchor, located away from the diver's exhalations, uncontaminated by sidelobes or multipath from the exhalations. The acceptance of an echo as scattered from a bubble cloud was based on a second acceptance criterion: freshly exhaled, uncontaminated by previous exhalations.



5

Fig. 5. The tracker used to review the sonar-centric images on a ping-by-ping basis.

The echo levels were converted to target strengths by comparison with the echo levels from a reference sphere of known target strength. The aspect angles were converted to diver's direction of motion by subtraction of 90 deg (clockwise procession around the anchor).

6 FIRST RESULTS

The first results, for the target strengths of a diver with air tanks, are presented in Fig. 6. The target strengths of the diver, not the diver's exhalations, are attributed to the scattering from lung cavities, suit and equipment. The scattering from human lung cavities is estimated at –27 dB on the basis of the strength of an acoustically-soft sphere of volume typical of human lung capacity (3 to 4 litres). The target strengths of the exhaled bubble clouds are attributed to the monopole vibrations of minute bubbles released in the exhalations.

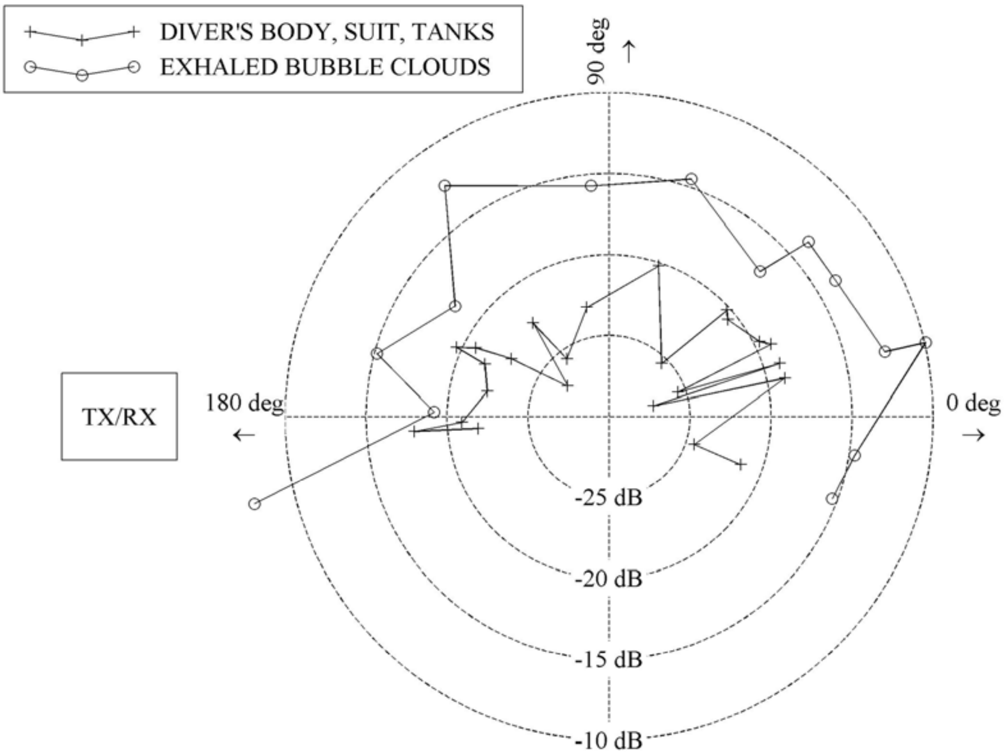


Fig. 6. The target strengths of a diver with air tanks at 100 kHz.

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